Deep Space Mission System (DSMS) Services Catalog

Version 7.0

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DSMS No. **820-100**
DOORS Baseline: **0.7**
Issue Date: March 27, 2002
JPL D-19002

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California Institute of Technology

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1 Purpose of the Document

The Deep Space Mission System (DSMS) is a consolidated system of the two JPL multi-mission systems, i.e. the Advanced Multi-Mission Operations System (AMMOS) and Deep Space Network (DSN), providing support to flight projects and science investigations. In general, the DSMS support to its customers can be categorized into 3 types:
(1) mission operations *services*,
(2) *tools* used by customers to operate their missions and to develop their mission operations system (MOS), and
(3) other *engineering support* such as those activities performed to support project mission design, telecommunication link analysis, end-to-end integration and test, etc.

In the past, distinctions between these 3 types of support were rather vague. As NASA moves into an era of full cost accounting, there is an urgent need for the DSMS to be the service providing system to all deep space missions. A clear definition of services and other two types of support is thus needed to delineate mission-specific capabilities (which must be developed or adapted by each flight project) and multi-mission services (which can be more readily available to any flight project), so that not only the most cost effective approach to building a project MOS is possible but also the best performance and cost accountability of service provision can be accomplished.

The DSMS Services Catalog defines standard mission operations services available to customers. Although many of the services defined here are applicable to deep space, Earth orbiting missions, and other mission domains, this service catalog in contents is intended mainly for deep space mission and high Earth orbit mission customers. Its specific usage can be summarized as follows:

(a) It provides a standard taxonomy of mission operations services as a basis for all customers to request support in areas of telecommunications and mission operations from DSMS. This approach differs significantly from the way that support was offered in the past, i.e. the provision of DSN assets (such as antennas) and AMMOS tools as the primary commodities to customers. The service definition is therefore an important input to the development of a service level agreement and other commitment documents between a flight project customer and the service provider.

(b) It provides some service pricing information for pre-project customers to derive life cycle cost estimates for their mission operations systems. This is crucial in an era of full cost accounting, as the mission selection process conducted by the various NASA Enterprises must take into account their expenditure on multi-mission support.

The Services Catalog is not a requirements or design document, nor is it an interface specification. For purpose of defining interfaces between the DSMS and project MOS, the catalog must be applied in conjunction with more detailed information covered in DSMS Telecommunications Link Design Handbook[1], AMMOS capabilities catalog and adaptation guide [4], and others.

It is a DSMS policy that the DSMS Services Catalog shall include only services that are available at the time of the catalog release, or have funded deployment plans and dates.

Throughout this document, the term *service* is applied to mean the mission operations service and the term *customer* refers to a flight project Mission Operations System (MOS) organization or an experiment investigator.

2 Point of Contact and Applicable Documents

The JPL DSMS Plans and Commitments Office will be the point of contact for making commitments to flight project customers on DSMS services, tools, and engineering support. For those services requiring special programmatic arrangement with JPL for subscription as identified in Table 5.1, please contact Dr. Fuk Li at (818) 354-2849. For information about how to contact the DSMS, please access the home page at URL address: http://deepspace.jpl.nasa.gov/advmiss

The custodian of the DSMS Services Catalog is the DSMS System Engineering Manager.

Reference Documents

Throughout this catalog, references to these documents are noted by superscripts corresponding the numbers in parentheses in the following list.

(1) DSMS Telecommunications Link Design Handbook, Document No. 810-5, Rev. E, Jet Propulsion Laboratory, Pasadena, California. URL address: http://eis.jpl.nasa.gov/deepspace/dsndocs/810-005/

(2) Telecommunications and Mission Operations Directorate Operations Contingency Plan, Rev. B, Document No. 801-202.

(3) Multimission Ground Data System: Users Overview, D-6057, Rev C, Jet Propulsion Laboratory, Pasadena, California, April 1994.

(4) Advanced Multimission Operations System (AMMOS) Detailed Capabilities Catalog and Adaptation Guide, D-5104, Jet Propulsion Laboratory, Pasadena, California.

(5) Space Flight Operations Center (SFOC) Functional Design Document, D-3752, Jet Propulsion Laboratory, Pasadena, California.

(6) Deep Space Network / Detailed Interface Design, Document No. 820-13, Jet Propulsion Laboratory, Pasadena, California.

(7) Telemetry Channel Coding, CCSDS 101.0-B-5, June 2001.

(8) Packet Telemetry, CCSDS 102.0-B-5, November 2000.

(9) Telecommand, Part 1: Channel Service, CCSDS 201.0-B-3, June 2000.

(10) Time Code Formats, CCSDS 301.0-B-2, April 1990.

(11) Orbit Data Messages. CCSDS 502.0-R-1. Red Book. Issue 1. June 2001.

(12) Space Link Extension Services - Cross Support Reference Model, Part 1: Recommendation for Space Data Systems Standards, CCSDS 910.4-B-1. Blue Book. Issue 1. May 1996.

(13) Space Link Extension - Cross Support Concept Part 1. CCSDS 910.3-G-1. Green Book. May 1995.

(14) Space Link Extension Return All Frames Service, CCSDS 911.1-R-2, Red Book, Issue 2. November 2000.

(15) Space Link Extension Forward CLTU Service, CCSDS 912.1-R-2, Red Book, Issue 2. May 2000.

(16) Space Link Extension Return Virtual Channel Frame Service, CCSDS 911.2-R-1, Red Book, Issue 1.

(17) A Guide to Capabilities Provided by the Office of Space Communications: NASA Office of Space Communications, April 12, 1996.

(18) Packet Telemetry Services, CCSDS 103.0-B-1. Blue Book. Issue 1. May 1996.

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(19) Advanced Orbiting Systems, Networks and Data Links: Architectural Specification, CCSDS 701.0-B-2. Blue Book. Issue 2. November 1992.

(20) Lossless Data Compression, CCSDS 121.0-B-1. Blue Book. May 1997.

(21) Radio Frequency and Modulation System, Part 1 - Earth Stations and Spacecraft, CCSDS 401.0-B, June 2001.

(22) CCSDS File Delivery Protocol (CFDP), CCSDS 727.0-R-5. Red Book. Issue 5. August 2001.

3 Definition of DSMS Services

3.1 Standard Service and Tailored Service

Service, in its general sense, is "work done for others". In the context of this document, a service is work performed by the service providing system, i.e. the Deep Space Mission System (DSMS), using one or more tools, facilities, or people, that produces mission and science operations results for a customer. Services may be standard or tailored.

DSMS standard services are those defined in this document, i.e. the DSMS Services Catalog, from which customers can make selection for their needed services to support their missions operations without significant expenditure of non-recurrent engineering to the customers.

A tailored service is one which requires substantial development effort due to the mission-dependent nature of the functions performed by the service or is one requested by customers for functionality different from a corresponding standard service offered in the DSMS Services Catalog. In either case, for fulfilling a tailored service, modification of DSMS capabilities with additional implementation effort will be needed at the cost of the customer.

3.2 Key Attributes of Standard Services

The DSMS standard services have the following key attributes -

(1) Customer Relevance: Services as perceived by the customers must be of value to the customers, packaged at a functional level, and expressed in the customer's terms. In other words, a service must be defined in terms of "what it provides" rather than "how it produces". This implies isolating the lower level of details of the capabilities and activities from the customers while still providing visibility to the customers.

(2) Pick-And-Choose: The services must be selectable by customers. Subscription to a service by a customer should not require buy-in of other services which are not relevant to the customer's needs.

(3) Plug-And-Play: The use of any standard services (as distinguished from the tailored services) must be based on definitions which appear in the DSMS Services Catalog. Once a service, as it exists in the Services Catalog, is subscribed to, it must be readily available for use by the customer. It should not require any implementation effort beyond interface testing, configuration setup, and parameter table updates, by the service provider.

(4) Standard Interfaces: The access to the DSMS services, in terms of control and data interfaces, by the customers will be via standard interfaces. "Standard" interfaces include those formally established by standards organizations (e.g., CCSDS, SFCG, ITU, ISO), those widely applied by the industry as de facto standards, and those defined by DSMS as common mechanisms to all customers. No additional development effort on the DSMS or the subscriber's system other than that required for conforming to the standard interfaces will be necessary.

(5) Service Control: The customers will be allowed to directly control the service (within the bounds of the system's capabilities and safety criteria).

(6) Interoperability: Services will be standardized, whenever applicable, to enable interoperability with other service providers whenever the same service is requested.

(7) Performance Accountability: Performance of each individual DSMS service subscribed to by a customer will be measurable and reportable.

(8) Cost Accountability: Services will be provided to a customer on a fee schedule basis. This means all standard services will be defined, structured, and priced in such a way that customers' recurrent costs can be visible.

(9) Mission Life Cycle Orientation: Although each service by nature is for supporting the mission operations of flight projects, there are activities which must be conducted by the DSMS during the design, implementation, and integration and test phases of the project in order to make a service available. These activities are inherent part of a service subscribed by the customer. As such, services are not defined according to the mission phases.

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4 DSMS as a Service Provision System

4.1 Customer Interface View

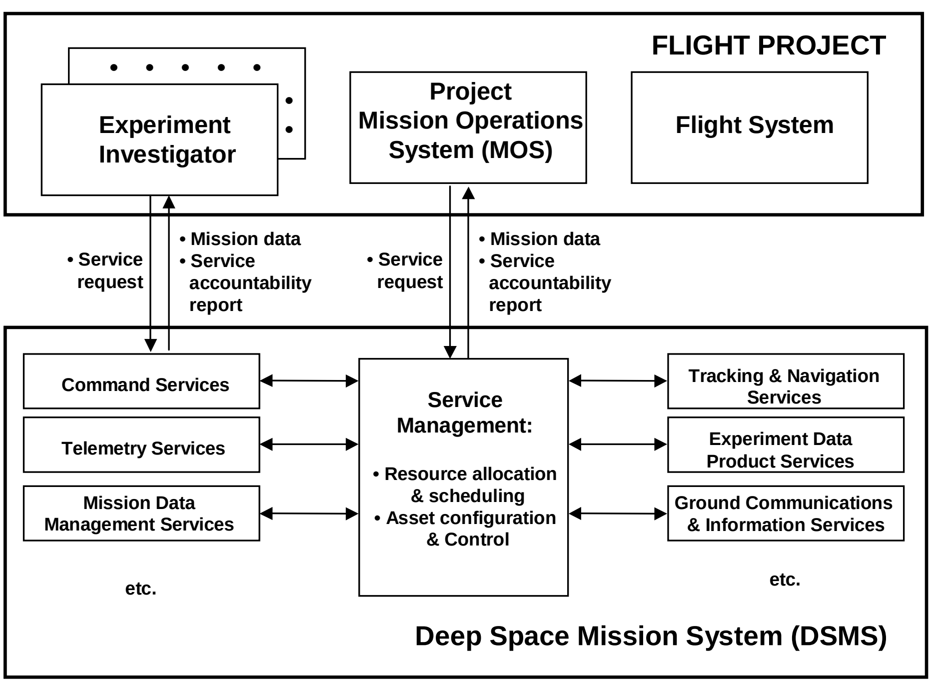
Figure 4.1 depicts the DSMS as a service providing system from the customer interface view. Key characteristics of the system from the customer interface view are as follows:

(1) Service Management function - This is a distributed function with its elements residing at the JPL DSMS Central and 3 Deep Space Communications Complexes (DSCCs). It includes (a) the allocation and scheduling of telecommunications and mission operations resources during service selection, agreement, and negotiation phases, (b) configuring and controlling the DSMS assets at DSMS Central and each DSCCs for service production during service utilization phase, e.g. before, during, and after a pass. With respect to (b), the service management function "monitors" and "controls" the service production and provision process.

(2) Service requests are used by a customer, as a mechanism, to interface with the DSMS for services. Service requests are input to both (a) resource allocation and scheduling, and (b) asset configuration and control, providing a seamless interface to customers for their service need. In fact, the current processes, i.e. long range resource allocation, mid-range scheduling, near-real-time scheduling, and real-time configuration and control, will become a single integrated process.

(3) All services performed by the DSMS will be readily accountable to customers. Service accountability report detailing the quality, quantity, continuity, and latency (QQCL) or other performance metrics about each instance of service will be provided to customers after the fulfillment of the services.

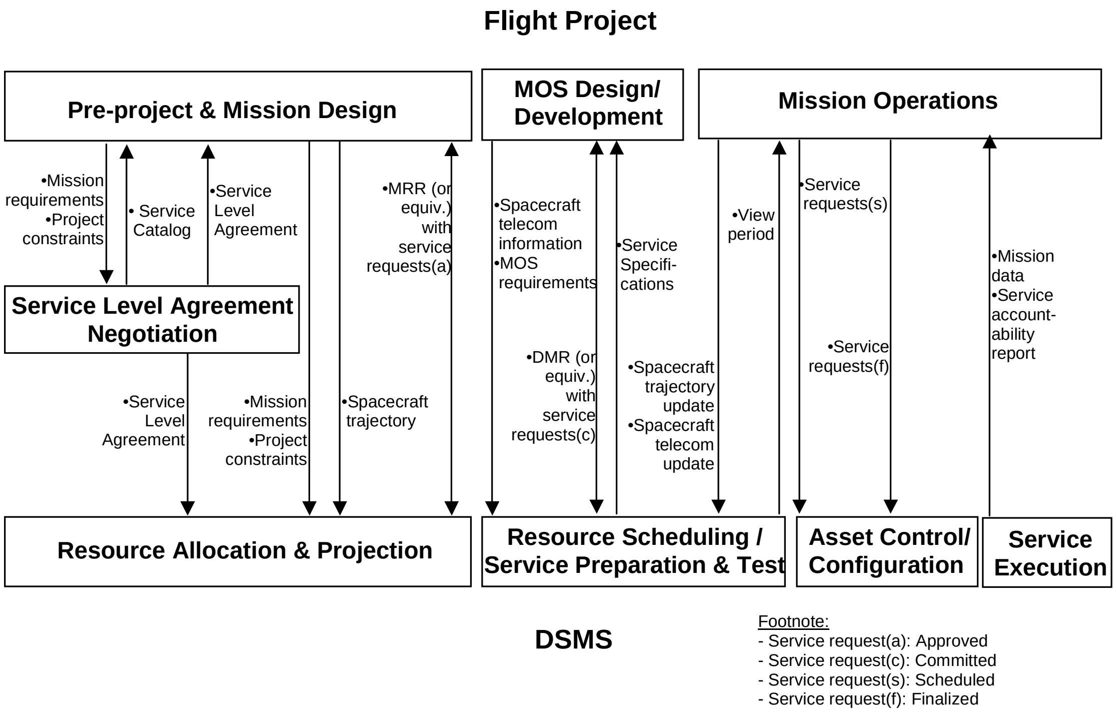
Figure 4.1 DSMS as a Service Providing System: Customer Interface View



4.2 Life Cycle Process View

Figure 4.2 shows the process for customer to interface with DSMS for services over the entire project life cycle.

Figure 4.2 Customer Interface for Services: Process Over Project Life Cycle



4.3 Physical Assets View

The DSMS services are visible and meaningful to customer in a functional sense. Many of these services are dependent on the spacecraft/ground links, the key physical assets available through its tracking networks, and the multi-mission data system capabilities. The Deep Space Network (DSN) provides operations support to deep space missions and some Earth orbiting missions. Functions provided by the DSN include tracking, telemetry, command, and ground-based science data acquisition services.

In DSN, there are 3 Deep Space Communications Complexes (DSCCs), located near Goldstone, California; Madrid, Spain; and Canberra, Australia. Each complex has at least a 70-m antenna, a 34-m High Efficiency (HEF) antenna, a 34-m Beam Waveguide (BWG) antenna, and a 26-m antenna. Figure 4.3 gives a summary about the DSN assets and their locations. These stations communicate with and track spacecraft at S- or X-band (in 34-m and 70-m cases both). A few of the 34-m BWG stations are also equipped with Ka-band capability. Table 4-4 contains a summary of the RF capabilities of all the DSN stations.

The specific functions that the DSN performs are:

To acquire telemetry data from spacecraft

To transmit commands to spacecraft

To track spacecraft position and velocity

To perform very-long-baseline interferometry observations

To measure phase and amplitude variations in radio waves for radio science experiments

To gather other science data for ground based experiments

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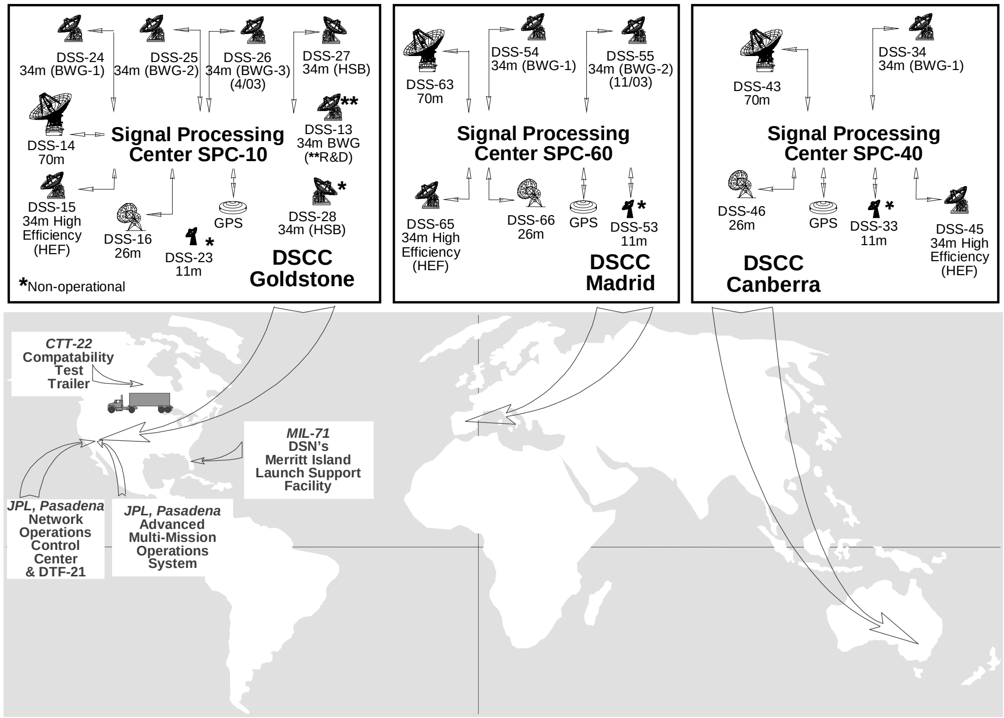
Figure 4.3 DSMS Physical Assets and Locations



Key characteristics of the DSN physical assets are described in the DSMS Telecommunications Link Design Handbook[1].

In addition to the 3 DSCCs, the DSN also includes a Network Operation Control Center (NOCC) in Pasadena, California; various emergency, test, and support facilities; and the people who operate and maintain these.

The AMMOS is made up of a collection of software tools, data processing elements, and the people who operate and maintain these to support flight project mission operations. The components of AMMOS are deployed at various MOS sites including JPL and several contractor facilities.

The combination of the NOCC, AMMOS, and various test and support facilities in Pasadena are referred to as “DSMS Central” in this document.

Table 4.4 DSN Stations and RF Capabilities (next page)

Antenna Dia (m)	Type	Location	DSS No.	Date On-Line	S-Band Uplink	S-Band Downlink	GAIN / G/T (Note 16) @ 45 deg (dB)	X-Band Uplink	X-Band Downlink	GAIN / G/T (Note 16) @ 45 deg (dB)	K-Band Uplink	K-Band Downlink	GAIN / G/T (Note 16) @ 45 deg (dB)	Rcvr Type
26	E.O.[1,4]	Goldstone, CA USA	16	Exist.	2025 - 2120[9]	2200 - 2300	52.5 / 31.7	-	-	-	-	-	-	MFR
26	E.O.[1,4]	Canberra, Australia	46	Exist.	2025 - 2120[9]	2200 - 2300	52.5 / 31.9	-	-	-	-	-	-	MFR
26	E.O.[1,4]	Madrid, Spain	66	Exist.	2025 - 2120[9]	2200 - 2300	52.5 / 31.8	-	-	-	-	-	-	MFR
34	BWG-1[1,3]	Goldstone, CA USA	24	Exist.	2025 - 2120[11]	2200 - 2300	56.7 /41.3	12/13/02[5,6,9]	8400 - 8500	68.0 / 53.8	-	10/1/06[5,7]	79.0/64.4[19]	Blk. V
34	BWG-1[1,3]	Canberra, Australia	34	Exist.	2025 - 2120[11]	2200 - 2300	56.7 /40.8	7145 - 7190[14]	8400 - 8500	68.2 / 52.3	-	11/30/05[5,7]	79.0/64.4[19]	Blk. V
34	BWG-1[1,3]	Madrid, Spain	54	Exist.	2025 - 2120[11]	2200 - 2300	56.7 /41.0	7145 - 7190[14]	8400 - 8500	68.2 / 53.1	-	8/1/07[5,7]	79.0/64.4[19]	Blk. V
34	BWG-2[1,3]	Goldstone, CA USA	25	Exist.	-	-	-	7145 - 7190[14]	8400 - 8500	68.3 / 53.1	34200 - 34700[15]	31800 - 32300	79.0 / 64.2	Blk. V
34	BWG-2[1,3]	Madrid, Spain	55	11/1/03[5]	-	-	-	11/1/03[5,6,9]	11/1/03[5]	68.4/55.8[19]	-	11/1/03[5]	79.0/64.4[19]	Blk. V
34	BWG-3[1,3]	Goldstone, CA USA	26	4/2/03[5]	-	-	-	4/2/03[5,6,9]	4/2/03[5]	68.4/55.8[19]	-	4/2/03[5,7]	79.0/64.4[19]	Blk. V
34	HEF[1,3]	Goldstone, CA USA	15	Exist.	-	2200 - 2300	56.0 / 39.9	7145 - 7190[9]	8400 - 8500[17]	68.2 / 53.5	-	TBD[5,7]	-	Blk. V
34	HEF[1,3]	Canberra, Australia	45	Exist.	-	2200 - 2300	56.0 / 39.8	7145 - 7190[9]	8400 - 8500[17]	68.2 / 53.4	-	TBD[5,7]	-	Blk. V
34	HEF[1,3]	Madrid, Spain	65	Exist.	-	2200 - 2300	56.0 / 39.2	7145 - 7190[9]	8400 - 8500[17]	68.2 / 53.4	-	TBD[5,7]	-	Blk. V
34	HSB[1]	Goldstone, CA USA	27	Exist.	2025 - 2120[10]	2200 - 2300	55.1 / 34.5	-	-	-	-	-	-	MFR
34	HSB[2]	Goldstone, CA USA	28	-	-	-	-	-	-		-	-	-	-
70	D.S.[3]	Goldstone, CA USA	14	Exist.	2110 - 2120[11,12] 2090 - 2094[13]	2270 - 2300	63.3 / 50.8	7145 - 7190[9]	8400 - 8500	74.3 / 62.7	-	TBD[5,7]	-	Blk. V
70	D.S.[3]	Canberra, Australia	43	Exist.	2110 - 2120[11,12] 2090 - 2094[13]	2270 - 2300	63.3 / 50.7	7145 - 7190[9]	8400 - 8500	74.5 / 62.8	-	TBD[5,7]	-	Blk. V
70	D.S.[3]	Madrid, Spain	63	Exist.	2110 - 2120[11,12] 2090 - 2094[13]	2270 - 2300	63.3 / 50.4	7145 - 7190[9]	8400 - 8500	74.3 / 62.3	-	TBD[5,7]	-	Blk. V

NOTES:

1. These stations can be used for Earth Orbiting (Category A) missions.
2. This High Speed Beam-Waveguide (HSB) antenna is not operational at this time.
3. These stations are used for Deep Space (Category B) missions.
4. These 26M stations may be closed in the future if a viable commercial substitute is available.
5. Planned Operational Date.
6. 7145-7190 MHz.
7. 31800-32300 MHz.
8. 34200-34700 MHZ.
9. Transmit power range: 200 W to 20 KW (23 to 43 dBW).
10. Transmit power range: 50 W to 200 W (17 to 23 dBW).
11. Transmit power range: 500 W to 20 KW (27 to 43 dBW).
12. Transmit power range: 5 KW to 400 KW (37 to 56 dBW).
13. Transmit power range: 5 KW to 150 KW (37 to 51.8 dBW).
14. Transmit power range: 200 W to 4 KW (23 to 36 dBW).
15. Transmit power range: 8 W to 800 W (9 to 29 dBW).
16. Performance values based on 45 deg. Elevation, vacuum conditions and Diplexed (if possible) single band mode.
17. 8200 - 8600 MHz for VLBI Service.
18. 20 KW transmitter planned.
19. Estimated values.

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5 DSMS Standard Services

Table 5.1 contains a list of DSMS Standard Services. Presently there are 11 *service families* (categories) defined. A *service family* is a collection of functionally related *service types*. Each *service family* contains one or more types of service. A *service type* is characterized by the unique function performed and the result produced by that service. Within a *service family*, the various *service types* are distinguished from one another by the level of processing involved, their value-added function, or the type(s) of source data. Numbers in Table 5.1 correspond to the *service descriptions* found in Section 6.

Table 5.1 List of Standard Services (V.20)

1. Command services:	**5. Experiment data product services**:**
• Command radiation service	**• Level 1 processing service****
• Command delivery service	**• Science visualization service****
2. Telemetry services:	**6. Flight engineering services**:**
• Bit stream service*	**• Telecommunication link analysis service****
• Frame service	**• Spacecraft time correlation service****
• Packet service	
• Telemetry channel service**	**7. Beacon tone service**
• Telemetry file service	
3. Mission data management services:	**8. Ground communications services:**
• Short-term data retention service	**• Ground network service**
• Long-term data repository service	**• Data transport service**
• Archive product preparation service**	
	9. Radio science services:
4. Tracking & navigation services:	**• Experiment access service**
• Raw radio metric measurements service*	**• Data acquisition service**
• Validated radio metric data service	
• Delta-DOR service	**10. Radio astronomy/VLBI services:**
• Orbit determination service***	**• Signal capturing**
• Trajectory analysis service***	**• VLBI data acquisition**
• Maneuver planning/design service***	**• VLBI correlation**
• Navigation ancillary data service	
• Ephemerides service	**11. Radar science services:**
• Modeling and calibrations service	**• Experiment access service**
• Gravity modeling**	**• Data acquisition service**
• Cartography**	

Notes:

* Services which are being decommissioned and not available to new missions.

** Services which are not part of the basic TT&C services and, therefore, require additional programmatic arrangement with JPL for subscription.

*** Services which are not part of the basic TT&C services and, therefore, require additional programmatic arrangement with JPL for subscription EXCEPT for LEOP support for DSN tracking purpose.

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6 Service Description

Two Command Services, termed *Command Radiation* and *Command Delivery*, are available to transmit data to a spacecraft. Table 6.1 summarizes the characteristics of these two services types. Users of this service should also consult Sections 7.1 and 8.1 to identify alternative configurations and performance characteristics.

6.1 Command Services

The Command Services transmits command data to the spacecraft. By functionality this service family is further divided into command radiation service and command delivery service. Table 6.1 summarizes the various service types and their associated data modes and protocols.

6.1.1 Command Radiation Service

Command Radiation is the more rudimentary of the two services. It can be operated in either a *Stream Mode* or a *File Mode*. In the stream mode, data in the form of Command Link Transmission Units (CLTUs) is received from a Project's MOS and radiated in real-time to a spacecraft as a string of *data units*. Conversely, in a file mode, a command file is stored at AMMOS or at DSMS Central prior to, or during, a pass and radiated to the spacecraft at a customer-specified time. Both modes ensure timely radiation of command data; however, error-free command delivery to the spacecraft is not guaranteed.

The Command Radiation *Throughput* [6] mode is being decommissioned and is not available to missions launching after April 2002. Beginning in May 2002, the CCSDS Space Link Extension (SLE) CLTU [15] becomes the standard DSMS stream mode for the command radiation service and will be used for the CONTOUR and INTEGRAL missions.

6.1.2 Command Delivery Service

Command Delivery is a more comprehensive service. It accepts command files from a Project's MOS in either real-time or at any point prior to the time designated for radiation. Using the standard CCSDS File Delivery Protocol (CFDP) [22], this service controls command radiation while providing reliable "error-free" delivery of command data to a spacecraft.

CFDP will be operational in August 2003 to support Deep Impact mission launching in 2004.

Table 6.1 Command Services: Service Types, Data Modes, and Protocols

Command Service Type	Data Mode	Protocol & Interface Specification
Command Radiation Service	Stream mode	Throughput: JPL CMD-4-9[6] CCSDS SLE Forward CLTU Service[15]
	File mode	JPL AMMOS SIS[3]
Command Delivery Service	File mode	CCSDS File Delivery Protocol (CFDP)[22]

6.2 Telemetry Services

Telemetry Services acquire, process, store, and deliver telemetry data products to a project MOS. Services are provided at five different levels, selectable by flight projects, and subscription to a higher level automatically provides all lower level services. These are:

1 Bit Stream
2 Frame
3 Packet
4 Channel Data
5 File Level

Users of this service should also consult Sections 7.2 and 8.2 to identify alternative configurations and performance characteristics.

6.2.1 Bit Stream Service

The Bit Stream Service provides a series of data units. Each data unit contains a stream of hard symbols or convolutionally decoded bits, in the order received, with an undetermined starting point, and without value-added processing such as frame decoding. Certain metadata is appended (e.g., received time of a certain bit, spacecraft ID, spacecraft bit rate, SNR, etc.).

Since the status of this product cannot be derived without further processing, the *quality* of this service is not guaranteed. Consequently, this service is available only to legacy missions and is being decommissioned.

6.2.2 Frame Service

Frame Service is available to missions having a supported modulation technique and: 1) a frame structure compliant with the CCSDS *Packet Telemetry* [7, 8, 18] recommendation or 2) a fixed length frame, where each frame is preceded by a CCSDS compliant synchronization marker. Within this service, the following frame output options are available:

6.2.2.1 All Frame Service

All Frame service[14] provides both actual data frames and filler frames

6.2.2.2 Virtual Channel Service

Virtual Channel service[16] provides data frames, i.e., virtual channel data units (VCDUs), selected, subset, and ordered within each virtual channel ID.

6.2.3 Packet Service

The Packet service extracts packets from frames, i.e. virtual channel data units (VCDUs), and delivers them to either project MOS or individual investigator. Compliance by the spacecraft with the CCSDS packet telemetry recommendation[8, 18] is essential to use this service. Two options of packet output are offered to customers:

Extracted packets are ordered by Earth received time.

Extracted packets are ordered by a combination of user specified mission parameters (e.g., application ID, packet generation time, packet sequence number, etc.).

6.2.4 Telemetry Channel Service

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

Telemetry Channel service extracts all samples of engineering measurements from telemetry packets pursuant to a set of pre-defined decommutation rules or measurement identification numbers. Samples are converted from Data Numbers (DNs) into Engineering Units (EUs).

6.2.5 Telemetry File Service

The Telemetry File Service acquires telemetry data units transmitted by a spacecraft, assembles these data units into individual files, submits the files to a data base, and notifies the MOS and the investigators that the data is available. In essence, this service enables the moving of a file from a spacecraft datastore to a MOS datastore. The CCSDS File Delivery Protocol (CFDP)[22], a content-independent protocol, which requires no knowledge about the information contents being transferred.

The DSMS can operate in either the unacknowledged mode or in one of the acknowledged modes. In an unacknowledged mode data delivery failures are not reported to the spacecraft foreclosing the automatic resending of the missing data. Accordingly, reception of complete files is not guaranteed. Conversely, in an acknowledged mode, the DSMS notifies the spacecraft of undelivered file segments or ancillary data. Missing items are retransmitted from the spacecraft guaranteeing complete file delivery.

The service provides the following capabilities:
(1) The ability of requesting a listing of the contents of a specified directory in the spacecraft's telemetry store.
(2) The ability of requesting a report of the status of a specified file transmission by the spacecraft.
(3) The ability to request the suspension and resumption of a specified file transmission by the spacecraft.
(4) The ability to initiate the delivery of a file from a spacecraft to a MOS or an investigator.

6.3 Mission Data Management Services

6.3.1 Short-Term Data Retention Service

The short-term data retention service provides reliable distribution of mission data to customers. It includes buffering, staging, and safe-keeping of mission data until custody has been transferred, either via an automated custody transfer protocol or manual acknowledgement. The maximum retention period is for 30 days from data acquisition.

Data types supported by this service include all data directly related to the spacecraft, i.e. command data, telemetry, tracking and navigation data, as well as associated meta-data.

6.3.2 Long-Term Data Repository Service

The long-term data repository service provides life-of-mission storage and retrieval of mission data in support of mission operations. The service includes provision of a catalog of all data in the mission repository. Users may query this catalog for data to be sent to them or re-staged on-line for retrieval. Data can be retrieved by time and data type and provided to the customers either electronically or on physical media.

Data types supported by this service include all data directly related to the spacecraft, i.e. command data, telemetry, tracking and navigation data, as well as associated meta-data.

6.3.3 Archive Product Preparation Service

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

The **archival product preparation service** packages spacecraft data, along with supporting meta-data and ancillary data provided by the project, into a form suitable for submission to permanent archives such as the Planetary Data System. Actual submittal and verified transfer of custody are included in the service.

6.4 Tracking and Navigation Services

6.4.1 Raw Radio Metric Measurement Service

This service provides radio metric observables based on measurement of phase and light time delay of the modulated RF signal acquired by the tracking stations. The data are not validated, except for a limited number of internal data validity flags, e.g. signal in lock, signal-to-noise ratio. The data are available electronically and the format is dependent upon the type of tracking station. All radio metric measurement services are also available as validated data via the Validated Radio Metric Data Service. It is recommended that users utilize the latter service.

6.4.2 Validated Radio Metric Data Service

The formats in which radio metric data is represented include a substantial amount of configuration data necessary for gleaning navigational use from the data. Due to a number of scenarios, this configuration data may be incorrect, rendering the radio metric observables unusable. The Validated Radio Metric Data Service validates incoming data and, when possible, fixes incorrect configuration data and supplies missing data (such as transmitter frequency). Data which can not be validated may be delivered to the customer, but are identified as such. All Doppler, ranging, and angle data are validated, and all data are delivered in the same DSN format, TRK-2-18[6]. It is recommended that all customers use validated data rather than raw data. To receive validated data, the subscriber simply requests the service and the specified data type.

6.4.3 Delta-DOR Service

The differenced differential one-way ranging (delta-DOR) technique provides an observation of the plane-of-the-sky position of a spacecraft, using signals received simultaneously at two or more antennas. In this technique, a spacecraft emits two or more sidetones separated from its carrier by large frequency offset, typically tens of MHz. Each of these tones is recorded at two stations simultaneously. A short time earlier and later, a quasar is observed with the same pair of stations. The signals are analyzed afterwards to calculate the delta-DOR observable.

Due to the need for different treatments of systematic error sources depending on details of the observing conditions, the components of the delta-DOR measurement are reported individually along with the aggregated measurement. Specifically, the data provided to the customer is a set of station-differenced phase offsets, differential one-way range, and interstation clock offsets for each source, time, and frequency measured. The data are delivered in the DSN format, TRK-2-18[6]. Quality assessments are also provided with the data, based on a large number of quality indicators both taken with the data and inferred during signal processing.

To receive validated delta-DOR data, the subscriber negotiates the times of spacecraft and quasar observations, and requests the service. A number of factors must be considered concerning the time and geometry of the session in order to obtain successful results; therefore DSMS provides assistance in the scheduling. The subscriber then arranges that their spacecraft is on earth point, with DOR tones turned on, at the planned time of observation. Important side-effects of the delta-DOR session are: (1) spacecraft telemetry may be degraded when the DOR tones are on, and (2) all other radio services (telemetry, command, radio metrics) will not be available during the quasar observations, because the ground antennas must be pointed away from the spacecraft.

6.4.4 Orbit Determination Service

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

The DSMS provides to the subscriber an option to request an orbit determination service rather than simply requesting raw radio metric tracking data. With this service the user receives updated trajectory solutions for the subscriber's spacecraft. The subscriber identifies the accuracy to which the spacecraft's trajectory must be known as a function of time. If the accuracy requirement is a prediction requirement, then the customer must also provide information as to how far in advance the trajectory knowledge must be determined. Based on these requirements, the orbit determination service will determine a tracking scenario to meet this request, schedule the needed resources, and process the data to provide the customer with spacecraft trajectory knowledge or prediction to the specified accuracy. Due to the geometry dependencies and scheduling requirements, the accuracy requirements for orbit determination services must be defined three to six months in advance for deep space missions and several weeks in advance for Earth orbiting missions. The customer will receive the spacecraft trajectory at requested times (in NAIF SPK format) and the associated uncertainties. The orbit determination service is offered in a few different ways depending on data types and processing modes. A brief description is as follows.

6.4.4.1 Radio Metric Orbit Determination

The radio metric orbit determination provides the orbit determination for those customers with Earth orbiting or deep space missions who rely exclusively on radio metric observables. It includes launch support and support of transfer phases of missions. Trajectory updates are available at predetermined intervals, but thirty minutes to two hours, at minimum is generally required for the processing of data. The limiting accuracy of this capability is dependent on spacecraft trajectory.

6.4.4.2 Optical Orbit Determination

This capability provides orbit determination services related to the use of optical measurements from an on-board camera. At the request of the customer, it can:
(1) provide a performance analysis for a given on-board image acquisition system,
(2) plan a schedule of observations to meet a customer defined trajectory accuracy either in conjunction with radio metric tracking or with optical data alone, or
(3) process the optical images (telemetered from the spacecraft) either alone or with radio metric data to provide an updated spacecraft trajectory.
As with the other orbit determination capabilities, the user requests a trajectory with a given accuracy over a time interval. The customer must specify if this accuracy requirement is relative to a specified target body (e.g. a planet or an asteroid) or inertial. If a trajectory prediction is required, the customer must specify how far in advance the prediction is required.

6.4.5 Trajectory Analysis Service

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

This service provides flight path prediction, reconstruction, and/or optimization to service subscribers. Flight path prediction consists of generating a detailed trajectory based upon state vectors, and associated spacecraft maneuver and body force modeling parameters. This allows for the generation of reference trajectories to be used for the tracking and mission predicts. Flight path reconstruction consists of generating a posterior reference trajectory based on orbit determination solutions and force models provided either by the customer or the orbit determination service. The trajectory optimization service will provide an optimized trajectory (from a deterministic delta-V perspective) based either on an approximate trajectory provided by the subscriber or based on a series of trajectory constraints (e.g. flyby conditions, entry conditions, & times).

6.4.6 Maneuver Planning & Design Service

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

This service provides propulsive maneuver analysis for flight missions and for future mission analysis. Based on a reference trajectory, the subscriber can request injection dispersion and probability of impact analysis for a specified launch vehicle as well as required aim-point biasing to meet planetary quarantine requirements. The subscriber may also request statistical delta-V analysis to characterize propellant needs, based on a trajectory, an expected orbit determination performance, and spacecraft thruster characteristics. This analysis will provide to the customer the optimal placing and sizing of maneuvers as well as estimates of the mission propellant needs. Orbit maintenance maneuver design, or the design of maneuvers required to change the orbit for the next mission phase is also available.

6.4.7 Natural Body Ephemeris Services

Natural Body Ephemeris Services provide ephemerides for all planets, most natural satellites, and several thousand comets and asteroids. The subscriber requests the service by specifying a period of time, the body or bodies of interest, and, if relevant, the desired accuracy of the ephemeris. If an ephemeris is already extant, which covers the desired period to the desired accuracy, it is immediately available. If the ephemeris is not available to the required accuracy, it may be possible to generate an improved ephemeris based on reprocessing of existing data or by acquiring additional data (generally for comets & asteroids). It may require from months to years to acquire the needed data and generate the new ephemeris. If the subscriber wishes, the service includes all of the analysis and scheduling of data acquisition.

6.4.7.1 Planetary Ephemerides

A single planetary ephemeris includes the trajectories (represented as polynomials over arbitrary time intervals) of the Sun, the Earth, the Moon, and 8 planetary system barycenters relative to the solar system barycenter. The accuracies to which each of the planets is known vary from the order 1 km for Venus and Mars, to the order of 10,000 km for Pluto.

6.4.7.2 Satellite Ephemerides

A single satellite ephemeris data set includes the ephemerides of a set of natural satellites and the parent planet relative to the barycenter of the particular planetary system. Satellite ephemerides are based on ground observations, radar measurements, and measurements from previous interplanetary missions.

6.4.7.3 Asteroid & Comet Ephemerides

Ephemerides are available for 14,000 asteroids and comets, including main belt asteroids and many Earth crossing asteroids and comets. An ephemeris can be generated at user request for any one of these bodies.

6.4.8 Modeling & Calibration Services

This service provides the subscriber with calibrations needed to process tracking data to the fullest accuracy possible. Calibrations specifically related to the data acquisition hardware are automatically delivered to subscribers of those data. These calibrations deal with systematic error sources which affect data.

6.4.8.1 Terrestrial Frame Tie

In order to process DSN radio metric data, the subscriber must know the inertial position of the receiver and, if appropriate, the transmitter at the time of the measurement. Although the locations of DSN antennas are known to within centimeters and the baselines between them to millimeters, the variations in polar motion and the rotation rate of the Earth can move the inertial position by much larger amounts than this. The terrestrial frame time data provides a temporal model for the orientation of the Earth's pole and the spin rate based upon VLBI observations and tracking of GPS satellites. This data provides the subscriber with an instantaneous knowledge of the inertial position of a crust fixed location on the Earth's equator to 30 cm. A posterior knowledge on the order of 1 to 5 cm is available after two to three weeks delay.

6.4.8.2 Transmission Media Calibrations

The transmission media through which the signals pass affects radio signals. The most significant of these are the Earth's troposphere and ionosphere. In order to achieve the data accuracies discussed in the previous sections on data services, it is necessary to calculate adjustments for the delays due to these. The media calibration models are based upon tracking of GPS satellites at two frequencies. The format of these calibrations is a history of zenith delay over a pass and a mapping function to map them to the appropriate altitude.

6.4.9 Gravity Modeling

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

The subscriber to the gravity modeling service can request and immediately receive an existing spherical harmonic gravity model for one of three bodies: Venus (120th degree and order), the Moon (75th degree and order), or Mars (50th degree and order). The subscriber can also request an improved gravity model based on provided tracking data; the improvement in the field will be based upon the accuracy and coverage of the data. The reduction of the tracking data and the generation of the improved gravity model will require some time to process. The amount of time is a function of the density of the data and current state of an existing model and will vary from a few days to a few months.

6.4.10 Cartography

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

The cartography service provides the subscriber with positions of landmarks on a body's surface which can be related to an inertial reference frame. The subscriber can either request the best current knowledge of a landmark based on previous analysis or in some cases, such as Mars landmarks, request an improved location estimate based on reprocessing of extant data. Finally, the customer may provide (or request to have provided from other services) image data and a reference trajectory and have the reference location of a specified landmark determined. The image data must include the inertial pointing of the imager and the time that the image was taken.

6.4.11 Navigation Ancillary Data Service

The Navigation Ancillary Data Service provides reduced and interpreted ancillary dataset to space scientists pertaining to their experiments. These data include spacecraft ephemeris, planetary ephemeris and constants, instrument descriptions, camera pointing, events about spacecraft and instruments, packaged in such a way that they are self-identifiable and correlated to science observations.

6.5 Experiment Data Product Services

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

The Experiment Data Product Services provided by DSMS to flight projects include the generation of a variety of experiment data products from the acquired science instrument data. The processing involved in generating these products applies high degree of multi-instrument capabilities, thus resulting in significant reduction in processing time and cost, and increase in product interpretability to the science team.

6.5.1 Level 1 Processing Service

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

Level 1 processing applies calibration information and ancillary data to remove the instrument signature from the data. The Level 1 processing service provides products generated in non-real-time after the arrival of the telemetry. Depending on the desires of the science team, the processing includes adding ancillary or correlative data, removal of instrument signature, mathematical transformation of time series data, reformatting of the data, and data quality check.

6.5.2 Science Visualization Service

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

Science visualization service takes science image data as input to produce still and animated visualizations for the planetary exploration missions, e.g. animated series for flights around Mars, Venus, Miranda, etc. The digital products of science visualization, when incorporated with navigation, ephemeris, or other imagery data, can be used for both science data analysis and science observation planning.

6.6 Flight Engineering Services

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

The Flight Engineering Services provide the spacecraft performance analysis, spacecraft and instrument health and safety monitoring, telecommunications link analysis, and spacecraft time correlation. Engineering support to assess spacecraft analysis on-board automation and autonomy design trades vs. requirements will be supported. In addition, Flight Engineering Services provide the engineering and planning required for execution of the real-time and non-real-time mission operations. The Flight Engineering Services also provide a project focal point for operations coordination, initiating commanding, on-line or on-call real-time anomaly response, and operations of non-standard/special circumstances.

6.6.1 Telecommunications Link Analysis Service

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

Telecommunications Analysis Service provides the means for a flight project customer to plan the communications configuration and capability between a spacecraft and the tracking stations of the Deep Space Network and then to assess the resulting performance against the plans. Planning requires the prediction of signal level, signal-to-noise ratio, and data error rate in terms of link models. Assessment requires the comparison of the values of these quantities as reported in spacecraft telemetry data and station monitor data against the predicted values.

The primary communications links are at any frequency supported by the stations. They include command, telemetry, and radiometric (closed-loop Doppler and turnaround ranging). The telecom analysis service can plan and assess relay links as well as those direct with the DSN.

A flight project can use the telecom analysis service at any time from initial spacecraft and mission design, through the implementation of a flight operations system, and into flight operations when the spacecraft-station communications links are active. It includes the following standard components:

Adaptation of the telecom link prediction and assessment tools. The tools provide a standard prediction, forecasting, and link performance comparison capability.

Set-up of link performance analysis displays involving standard or custom processing of in-flight data for comparison with predictions.

People to operate the tools and so provide pre-defined predictions or communications link analysis reports.

People to participate in the project's flight operations teams as telecom analysts at an agreed upon level of support.

Documentation of the project's telecom plans and support requirements, telecom configuration and performance predictions, and actual telecom performance relative to predictions.

6.6.2 Spacecraft Time Correlation Service

(NOTE: This service is not part of the basic TT&C services and, therefore, requires additional programmatic arrangement with JPL for subscription, prior to inclusion in proposal.)

The DSMS offers a Spacecraft Time Correlation Service which, with a cooperating spacecraft implementation, enables correlation of the time of spacecraft events with Coordinated Universal Time (UTC) and the time these events would be observed on the ground (earth received Time, UTC). Specifically, this service provides:

Validated correlation coefficients to convert spacecraft clock counts into spacecraft event time (UTC) for acquired data.

Predicted correlation coefficients to convert spacecraft clock counts into spacecraft event time (UTC) for future events (e.g., command execution times). This is achieved by modeling and monitoring the spacecraft clock and its drift characteristics.

The corresponding earth received time (UTC) for Validated or Predicted values of spacecraft clock count or spacecraft event time (UTC).

On-board UTC If the spacecraft carries an adjustable clock, DSMS can provide the service of measuring its offset from UTC (as above) and routinely commanding it to drift ahead or behind to eliminate or reduce the correlation coefficients to acceptable bounds. This enables the customer to use the spacecraft time tags as they appear in the data, without corrections.

To obtain this Service, the spacecraft timing implementation of future missions must:

use CCSDS Source Packets with time tags (in the secondary headers) which are derived from the spacecraft master clock which is being measured as part of this service,

use one of the CCSDS Time Code Formats[10],

use CCSDS Frames,

read the spacecraft clock at the time a specific bit of a telemetry frame leaves the spacecraft, and

report this time, plus the corresponding frame sequence number and Virtual Channel in either a dedicated Time Calibration packet or the Operational Control Field of a related frame.

6.7 Beacon Tone Service

The DSMS provides the Beacon Tone Service for the flight project MOS to monitor the high-level state of the spacecraft according to the beacon tones generated and transmitted by the spacecraft. The DSMS will be capable of acquiring and detecting the 4-tone Beacon Monitoring signals at SNRs down to 5 dB-Hz, with detection times up to 1000 seconds, on the 70-m, 34-m BWG and 34-m HEF stations. The detected tone will be forwarded to the project MOS as a message. However, the interpretation of the detected tone is the responsibility of the MOS. The committed date of this service is 20 June 2003.

For those missions, which have a long ion-powered cruise and confirming progress is needed during periods when the downlink signals drops below threshold for normal telemetry via LGA while on thrust attitude (for example, below a Pt/No of about 18 dB-Hz), the Beacon Tone Service offers a useful mechanism for the MOS to gain a minimum visibility into the health and safety of its spacecraft.

In a sense, the Beacon Tone Service is a special type of telemetry service.

6.8 Ground Communications Services

Ground Communications and Information Services provides a reliable and secure communications infrastructure capability to flight projects.

820-100 DSMS Services Catalog

6.8.1 Ground Network Service

Reliable communications are provided from the stations or JPL to the user's site, and the end-to-end integrity of the network is maintained by DSMS with a 24-hour per day, seven-day per week communications staff. Communication paths for data, voice, and video network between the mission control center, various PI facilities, various contractor facilities, the launch site, JPL, and DSCC are established via wide area network circuits and/or local area networks.

(1) Wide Area Networks: Ground communication circuits are provided from the antenna stations or JPL, to the user's site. DSMS orders the wide area network services from the NASA Integrated Service Network (NISN) Program. In turn, NISN orders domestic services through the General Service Administration's FTS 2000 contract (i.e., AT&T), and arranges special contracts for international circuits. Circuits that are used to carry spacecraft data are usually ordered with carrier guarantees for 20-minutes-to-isolate problems, and two-hour-to-restore.

Dedicated channels from the antenna stations through JPL can often be provisioned by multiplexing channels through a shared NISN circuit.

(2) Local Area Networks: Local area networks are installed and maintained by the DSMS network engineers. The most common LAN technology is Ethernet (10 Mbps, 100 Mbps, or Gigabits), which are used to form the backbone networks for high-speed access among various locations.

(3) Data Networks: Data networks are based on the Internet Protocol (IP). Among hosts at a particular site, Ethernet hubs and virtual LAN technology are used for ground communication. IP routers are used to transmit data traffic across a path of dissimilar networks. Routers and hubs may be installed and configured by the DSMS network engineers.

(4) Voice and Facsimile (Fax): DSMS supports dedicated voice loops for real-time communications between project operations centers (POCs) and antenna station operations. Compressed voice technology (from normal 64 kbps, down to 12 kbps) is usually used for these communications.

Fax transmission occurs over the same voice paths.

(5) Remote Communications Terminal (RCT): DSMS may provide a dedicated terminal for a user's site that includes circuit-termination equipment, voice interface equipment, a router, and remote testing equipment. The RCT may be configured for unattended operations.

6.8.2 Data Transport Service

At the DSN antenna stations, the station communications processor (SCP) receives all data generated by the digital receiver and telemetry processor. It may pass the data directly to the Project MOS and/or PI's sites as a low-latency UDP (User Datagram Protocol) stream or forward the stream to a reliable network service (RNS) that guarantees no lost IP packets. The RNS delivery service has several user options that are described below.

Low-Latency Service: The low-latency service is used to feed a real-time stream of spacecraft data to the user in the shortest possible time. This service is similar to the (now obsolete) NASCOM 4800-bit switched service. No error recovery is made; data packets that may be damaged by noise in the ground communications circuit are simply discarded. This is a legacy capability and is no longer offered to new missions.

Reliable Network Services:

Timely Service - Timely Service transmits a reliable real time stream to the user, but if the stream is delayed due to ground network congestion, any data older than 10 seconds is discarded. A simultaneous stream (complete) is forwarded to a data repository for later delivery. This makes it possible for the user to keep abreast of activity on the spacecraft, and have confidence that the data is complete within the specified time limits.

Complete Service - The Complete Service is used for most stream data. Congestion in the ground network may cause delays, but all the data will be delivered in the stream, and a simultaneous stream (complete) is forwarded to a data repository for later delivery. Delivery is guaranteed within 5 minutes.

Off-Line Service - All RNS data is stored for later, off-line, delivery. Delivery is accomplished using the File Transfer Protocol (FTP). After prior registration with the operations Communications Chief, the data may be delivered by FTP (1) automatically, (2) on command by the Communications Chief, or (3) on command by the user using a Web interface.

6.9 Radio Science Services

DSN Radio Science Services are provided to scientists to enable them to use of the Deep Space Network for direct scientific observations. The services deliver measurements of the spacecraft downlink signal from either open-loop or closed-loop receivers. Data from the open-loop receiver are digital recordings of the baseband signal derived from the received spacecraft signal at S, X, or Ka-band. Closed-loop data are measurements of the Doppler frequency and spacecraft range (see the Tracking Navigation Service description for more details).

The Radio Science Services are further divided into two types of service based on the level of operational activities involved:

Level 1 - Experiment Access. The first level of service is aimed at users with expertise in the DSN science capabilities and provides them with access to the equipment and technical assistance, including operations support and scientific collaboration when appropriate, to perform their experiments. In some cases access can be via remote operations terminals or onsite.

Level 2 - Data Acquisition. The second level of service provides raw measurements and ancillary data from observations. DSMS provides scheduling, experiment design, instrument operations, and data delivery based on agreements negotiated prior to the observations.

Key performance characteristics of radio science services in metrics such as frequency stability, phase noise, and amplitude stability, are described in Module 209, Open-Loop Radio Science, of Document 810-005, DSMS Telecommunication Link Design Handbook.

6.10 Radio Astronomy/VLBI Services

The Radio Astronomy/VLBI Services uses the DSN's large gain, low system noise temperature, and tracking stations to make observations of RF emitting astronomical sources. The Radio Astronomy capabilities are intimately related to the DSMS's R&D programs in science and technology. For observations within standard DSN communications bands, users are provided conditioned IF signals. These IF signals can then become input to either DSMS supplied special purpose receiving and data acquisition equipment being used for R&D or user supplied equipment. For observations outside the standard communications bands, investigators can use special purpose R&D microwave and receiving equipment, when available.

Radio Astronomers using DSN antennas as part of a network in Very Long Baseline Interferometry (VLBI) observations receive digitized and formatted samples of an open-loop signal on VLBA (Very Long Baseline Array) compatible tapes. VLBI observations are supported using a standard Mark IV VLBI data acquisition system. Correlation of VLBI data from up to four antennas is also available.

The Radio Astronomy/VLBI Services can be categorized into the following three types of services:

6.10.1 Signal Capturing Service

The Signal Capture service provides antenna pointing, radio frequency output, and/ or output at an intermediate frequency (downconverted from RF) for observations of natural radio emitters. R&D equipment or user supplied equipment, external to this service, is used to complete signal processing and data acquisition. Amplification and downconversion of signals is available at "standard" DSN communications frequencies defined in Document 810-005, DSMS Telecommunication Link Design Handbook. Use of special-purpose R&D equipment for observations at other frequencies and bands may be negotiated through the DSN Science Office.

6.10.2 VLBI Data Acquisition Service

The VLBI Data Acquisition service includes signal capture and utilizes the Mark IV VLBI Field System for data acquisition and recording. The Mark IV system, including the Mark IV data format, is a standard used at radio observatories throughout the world and is described in the reference document listed above in "applicable documents". This service includes delivery of data tapes to a user-designated correlator.

6.10.3 VLBI Data Correlation Service

The VLBI Data Correlation service provides the capability to cross correlate up to 4 data streams in the Mark IV format. Correlation is provided using the JPL VLBI Correlator, located in Pasadena, California.

Key performance characteristics of VLBI services in terms of accuracy of VLBI measurements are described in Module 210, Narrow Channel Bandwidth VLBI and Module 211, Wide Channel Bandwidth VLBI, of Document 810-005, DSMS Telecommunication Link Design Handbook.

Within the DSN downlink frequencies, the service provides conditioned IF distribution from S, X and Ka Band DSN radio frequency subsystems to special purpose receiving and data analysis subsystems. The latter are operated and maintained by various R&D engineering groups that differ among the three Deep Space Communication Complexes (DSCCs).

The service also provides monitor and control interfaces to DSN operational subsystems (e.g., antenna pointing, receivers, FTS) via Radar and Radio Astronomy special purpose control subsystems.

6.11 Radar Science Services

DSN Radar Science Services are provided to scientists to enable them to use of the Deep Space Network for direct scientific observations. The Radar Service provides observations from the Goldstone Solar System Radar (GSSR), a dual wavelength (3.5 cm and 12.5 cm), multi-aperture, high power, simultaneous dual polarization reception (RCP and LCP), radar. The GSSR can be operated in continuous wave or binary phase coded modes. Interferometric observations using up to four DSN receiving antennas are possible as are bi-static observations with the radar at the Arecibo Observatory or the Greenbank Telescope.

It is the only fully steerable planetary radar system in the world. This characteristic makes it extremely valuable for observations of Near-Earth asteroids and comets which typically encounter the Earth at a wide variety of declinations.

The Radar Science Services are further divided into two types of service based on the level of operational activities involved:

Level 1 - Experiment Access. The first level of service is aimed at users with expertise in the DSN science capabilities and provides them with access to the equipment and technical assistance, including operations support and scientific collaboration when appropriate, to perform their experiments. In some cases access can be via remote operations terminals or onsite.

Level 2 - Data Acquisition. The second level of service provides raw measurements and ancillary data from observations. DSMS provides scheduling, experiment design, instrument operations, and data delivery based on agreements negotiated prior to the observations.

The modes of operation of the GSSR fall into three broad categories, all at both 3.5-cm and 12.5-cm:

6.11.1 Continuous Wave (CW) Modes

There are three CW modes, each with different hardware subsystems (Normally both circular polarizations are received in CW observations.):

a) Narrow bandwidth. This mode is offered for targets whose received bandwidth spreading is no more than 40 kHz.

b) Medium bandwidth. This mode is offered for targets whose received bandwidth spreading is no more than 8 MHz.

c) Wide bandwidth. This mode is offered for targets whose received bandwidth spreading is no more than 40 MHz.

6.11.2 Binary Phase Coded (BPC) Modes

The possible modes provided are divided by received polarization diversity and the number of stations receiving. The transmitter subsystem can supply either right OR left circular polarization signals in the BPC mode. The receivers at DSS-14 and DSS-13 can be configured for both or either circular polarization. DSS-15 and DSS-25 can only receive a single polarization, with RCP or LCP at the experimenter's choice.

6.11.3 Interferometric Observations Modes

The GSSR can utilize the following baselines at the Goldstone Deep Space Communications Complex: DSS-14 to DSS-13, DSS-13 to DSS-25, DSS-13 to DSS-15, DSS-15 to DSS-25, and DSS-14 to DSS-25. The DSS-14 to DSS-15 baseline is too short for any practical application. In addition, the GSSR can transmit a CW signal designed to be used for direct imaging in both polarizations at the Very Large Array (VLA) of the National Radio Astronomy Observatories (NRAO, Socorro, NM) and the Very Large Baseline Array (data processing at the NRAO correlator in this case only, also in Socorro).

6.12 Service Management

Service Management is a special category of functions that must be performed by the customer and DSMS cooperatively to ensure that instances of services are properly planned and executed. It provides operational support to customers in preparation for the services they need, for controlling the production and provision of services, and for providing the visibility and accountability of DSMS service systems [Ref. to "CCSDS Space Link Extension - Cross Support Reference Model].

It includes (1) planning, scheduling, and allocating DSMS resources required for fulfilling the services (2) controlling and configuring DSMS assets required for providing the services. The service management functions typically performed by a customer and their respective interfaces are summarized as follows:

(1) Generating predicted spacecraft trajectory – via interface conforming to the CCSDS Orbit Data Messages standard[11] or SPK.

(2) Making schedule request - via interface conforming to the Schedule Request, OPS-6-12 document[6] or its variations.

(3) Providing spacecraft telecommunication events and link characteristics – via interface conforming to the Keyword Files, OPS-6-13 document[6] or its variations.

7 Alternative Configurations

DSMS facilities can be configured in different ways to better suit a user's requirements. This section provides a short description of possible configurations for the named services.

7.1 Command Configurations

The DSMS provides two command configurations. These are: Low Rate Command and Medium Rate Command.

7.1.1 Low Rate Command

Low Rate Command has been the typical configuration used for years. Command data units received by the DSMS from the Project's MOS are Phase Shift Key (PSK) modulated on a 16 KHz sine wave subcarrier such that the subcarrier is fully suppressed. This PSK modulated subcarrier is then modulated on an Earth station's RF carrier so as to leave a residual (ruminant) carrier component. Data rates from 7 1/2 bps to 4 Kbps can be radiated. Low Rate Commands comply with CCSDS Recommendation 401 (2.2.2) B-1. (Note: 1 Kbps in this context means 1,000 bps.)

7.1.2 Medium Rate Command

Command data units received by the DSMS from the Project's MOS are Bi-Phase (Bi-() modulated on an Earth station's RF carrier so as to leave a residual (ruminant) carrier component. Initially, data rates from 8 Kbps to 128 Kbps can be transmitted; however, the system will be upgraded to cover the proper range up to 256 Kbps when the need arises. Medium Rate Commands comply with CCSDS Recommendation 401 (2.2.7) B-1. (Note: 1 Kbps in this context means 1,000 bps.)

7.2 Telemetry Configurations

DSMS signal capture efficiency is influenced by several factors including: station-operating mode (diplexed v. non-diplexed), aperture size, operating frequency, and various station configurations. In addition to the standard one-station configuration, there are other alternatives. This section describes some additional capabilities.

7.2.1 Multiple Spacecraft Per Aperture (MSPA)

Multiple Spacecraft Per Aperture (MSPA) is a special configuration wherein multiple receivers are connected to a single DSN antenna permitting the simultaneous reception of signals from two or more spacecraft. MSPA makes more efficient use of DSN facilities by enabling simultaneous data capture services to several spacecraft, provided that they are all within the Earth station's beamwidth. MSPA is not a service; it is a capability for resolving some schedule conflicts.

Presently, the DSN can receive signals from two spacecraft simultaneously in a 2-MSPA configuration. By the conclusion of 2005, there are plans to support up to four spacecraft simultaneously in a 4-MSPA configuration.

MSPA design limits unlink transmissions to a single spacecraft at a time. Thus, only one spacecraft can operate in a two-way coherent mode, all others must be one-way non-coherent.

Only the spacecraft having the uplink can be commanded. However, MSPA users can agree to share the uplink, switching during the pass. Approximately 30-minutes are required to reconfigure the uplink to operate with a different spacecraft.

There are certain requirements for users to avail themselves of MSPA. First, all spacecraft must lie within the beamwidth of the requested DSN station. Second, all spacecraft must operate on different uplink and downlink frequencies. Third, commands can only be sent to the spacecraft having the uplink. Fourth, high quality (2-way) radio metric data can only be obtained from the spacecraft operating in the coherent mode.

7.2.2 Antenna Arraying

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Antenna Arraying is another special configuration wherein the signals from two or more DSN antennas are combined to create the performance of an antenna larger than either. Combining is done at an intermediate frequency (i.f.) resulting in improved performance of both the carrier and data channels. Arraying 34M antennas with a 70M station improves the performance of the 70M station. When operating in the 8 GHz band, approximately five 34M stations are required in an array configuration to equal the performance of a 70M station. Like MSPA, arraying is a capability, not a service.

8 Performance Characteristics

The service paradigm demands performance accountability for the services rendered. Where data delivery is involved, accountability requires a measure of the quantity, quality, continuity, and latency of the data delivered. This section addresses those subjects.

$$Q_{TY} = \frac{\text{Number of } \textit{acceptable} \text{ data units delivered}}{\text{Number of } \textit{acceptable} \text{ data units input to the service}}$$

8.1 Command Service Performance

8.1.1 Quantity

Quantity is defined as the volume of "acceptable" *data units* delivered by the service.

$$Q_{LTY} = \frac{\text{Number of data units correctly delivered}}{\text{Total number of data units sent over a properly operating RF link}}$$

Note: The number of *acceptable* data units used to compute QTY are based upon the number of complete and error-free *data units* either delivered or expected during the service time in which the performance of the RF link is equal to or better than that specified for the pass. *Quantity* is the primary measure of completeness.

For the command system, a *data unit* is a Frame, Packet, CLTU, or File, depending upon the type of service.

8.1.2 Quality

Quality is defined as the "error rate" for the delivered *data units* over the end-to-end path.

Data unit error rate depends upon whether or not coding is used and, if so, which particular scheme is employed.

Currently, commands are typically encoded by the Project's MOS with a BCH code providing a two error detection, one error correction capability. In the future more sophisticated codes, such as those used for telemetry, may become available.

8.1.3 Continuity

Continuity is defined as the number of gaps in the set of data units delivered to a customer during a scheduled pass. A gap is defined as the loss of one or more consecutive data units. *Continuity* is distinguished from *Quality* in that the former counts the number of gaps (holes) in the data set during a scheduled pass while the latter measures the percentage of the total number of data units returned to a customer during the same scheduled pass.

For the *Command Radiation Service*, gaps are not an issue when operating in the File Mode because all of the data is received by the DSMS prior to radiation. Likewise, gaps do not occur in the *Command Delivery Service* because complete, error-free delivery of all commands is guaranteed.

8.1.4 Latency

Latency is defined as the time delay between a data unit's transmission from a specified point and its delivery to another point where it becomes accessible to a customer.

For commands, the point of transmission is the Project MOS and the delivery is the beginning of actual command radiation by the DSMS. *Latency* includes delays in the communications system from the Project MOS to the DSMS and delays occurring within the DSMS until the command is actually radiated.

Command Radiation Service times can be specified and have accuracies of 0.1 seconds or (8 bit-times, whichever is greater. Latency is the sum of the delays specified above plus the radiation timing accuracies.

For the *Command Delivery Service* latency times are the sum of the delays specified above for the *Command Radiation Service* plus the time required to actually delivery of the command to the designated spacecraft.

8.2 Telemetry Service Performance

8.2.1 Quantity

Quantity is as defined in Section 8.1.1 above for command. For telemetry, *data units* are Frames, Packets, and Files. The DSMS routinely achieves 95% delivery during the life of mission; however, up to 98% is achievable (but not guaranteed) if special arrangements are made. These values are derived from an assessed probability of unrecoverable data loss based upon "system availability" statistics from the DSMS telemetry system. It must also be noted that use of acknowledged Telemetry File service will significantly improve the percentage of original data delivered.

8.2.2 Quality

Quality is as defined in Section 8.1.2 above for command. Telemetry *data units* typically use an error-detecting error-correcting code such as: Reed Solomon, convolutional, turbo, or some combination of these. Assuming a frame (or packet) length of approximately 10,000 bits, and a convolutional (r = 1/2, k = 7) code concatenated with a Reed-Solomon (223/255) block code the:

Frame Rejection Rate $\leq 10^{-6}$ at an $E_b/N_0 = 2.8$ dB (Bit-Error-Rate $\leq 10^{-8}$).

While a rate = $^1/3$ turbo code having a frame size of 8920 bits has a:

Frame Rejection Rate $\leq 10^{-4}$ at an $E_b/N_0 = 0.4$ dB (Bit-Error-Rate $\leq 10^{-7}$).

However, a rate = 1/6 turbo code with a block size of only 1784 bits provides a:

Frame Rejection Rate $\leq 10^{-5}$ at an $E_b/N_0 = 0.4$ dB (Bit-Error-Rate $\leq 8 \times 10^{-7}$).

Therefore, users should take care to determine their acceptable frame rejection rate and thereafter carefully select a coding scheme to provide the required performance.

Undetected error rate, introduced by ground equipment is less than 4×10^{-12}.

8.2.3 Continuity

Continuity is as defined in Section 8.1.3 above for command. Data units are Frames or Packets depending upon the subscribed service type.

For a frame (or packet) length of approximately 10,000 bits, the DSN routinely provides a gap rate less than or equal to 8 in 10,000 frames (or packets), for a frame (or packet) length of 10,000 bits provided:

1. The E_b/N_0 is sufficient for a Frame Error Rate ≤ 1 x 10^{-5} at all times during the pass.
2. There are no spacecraft anomalies throughout the pass.
3. The telemetry data rate does not change during the pass necessitating reacquisition.
4. No RFI events occur during the pass.

To obtain higher levels of continuity, special human intensive efforts are required during the pass. Potential users are advised to design their mission data return strategy to be tolerant of occasional gaps. A gap-rate of 8/10,000 frames (or packets) as described above should be expected as the nominal condition.

8.2.4 Latency

Latency is as defined in Section 8.1.4 above for command. For telemetry, three grades of delivery can be selected, subject to availability of adequate ground communications bandwidth.

Grade-1: (Timely Delivery) in which correct data units are delivered in order, without duplication, but with potential omissions resulting from excessive transmission latency, are provided with a typical latency of seconds. This grade is used along with *Off-Line Delivery* to retrieve omitted data.

Grade-2: (Complete Delivery) in which: all data, in correct order, without omission or duplication, are provided with a typical latency ≤ 5 minutes.

Grade-3: (*Off-Line Delivery*) is primarily used for data recall. It is also used for post-pass delivery to those customers whose receiving system is not *on-line* during the pass. Typical latencies can be hours.

All three grades use the reliable communication protocol, i.e., TCP, as underlying interface method. The difference is that the *timely delivery* allows for the controlled discarding of telemetry frames at the application layer if it is not possible to deliver those frames within a certain amount of time after they are acquired from the space link (e.g., because of communications service backlog).

8.2.5 Telemetry Data Acquisition - Throughput

Depending on the link performance, coding scheme, modulation method, and other factors, the DSN is presently capable of acquiring telemetry data at the maximum throughput of 2.2 Mbps and the minimum throughput of 10 bps (uncoded). By 2005, the maximum throughput for telemetry data acquisition will be increased to 4 Mbps for Reed-Solomon encoded data using convolution code (7, 1/2).

8.3 Radio Metric Measurement Service Performance

8.3.1 Doppler Data

Doppler data are the measure of the cumulative number of cycles of a spacecraft's carrier frequency received during a user specified count interval. The exact precision to which these measurements can be made is a function of received signal strength and station electronics, but is a small fraction of a cycle. Raw Doppler data is generated at the tracking station and delivered via DSN interface TRK-2-34[6], for 34m and 70m stations and in format TRK-2-30[6] for 26 m antennas. In order to acquire Doppler data, the user must provide a reference trajectory, and information concerning the spacecraft's RF system to DSMS to allow for the generation of pointing and frequency predictions.

The user specified count interval can vary from 0.1 sec to 10 minutes, with count times of 10 to 60 seconds being typical. The average rate-of-change of the cycle count over the count interval expresses a measurement of the average velocity of the spacecraft in the line between the antenna and the spacecraft. The accuracy of Doppler data is quoted in terms of how accurate this velocity measurement is over a 60 second count. The accuracy of data improves as the square root of the count interval.

(1) Noncoherent Doppler Data

Noncoherent data (also known as one-way data) is data received from a spacecraft where the downlink carrier frequency is not based on an uplink signal. The ability of the tracking station to measure the phase of the received signal is the same for non-coherent versus coherent data types, however the uncertainty in the value of the reference frequency used to generate the carrier is generally the dominant error source.

(2) Coherent Doppler Data

Coherent Doppler data is that received from a spacecraft where the reference frequency of the received carrier signal was based on a transmitted uplink signal from the Earth. This is commonly known as two-way data, when the receiving and transmitting ground stations are the same, and three-way data, when the transmitting and receiving stations are different. Since the frequency of the original source signal is known, this error source does not affect data accuracy. The accuracy of this data is a function primarily of the carrier frequency, but is affected by transmission media effects.

S-band: S-band (2.2 GHz) data is available from 26m, 70m, and some 34m antennas. The one-sigma accuracy of S-band data is approximately 1 mm/s for a 60 second count interval after being calibrated for transmission media effects. The dominant systematic error which can affect S-band tracking data is ionospheric transmission delays. When the spacecraft is located angularly close to the Sun, with Earth-spacecraft-Sun (EPS) angles of less than 10 degrees, degradation of the data accuracy will occur. S-band data is generally unusable for EPS angles less than 5 degrees.

X-band: X-band (8.4 GHz) data is available from 34m and 70m antennas. X-band data provides substantially better accuracy than S-band. The one-sigma accuracy of a 60 second X-band Doppler measurement is approximately 0.1 mm/s. X-band data is less sensitive to ionospheric media delays but more sensitive to weather effects. X-band data is subject to degradation at EPS angles of less than 5 degrees, but is still usable with accuracies of 1 to 5 mm/s at EPS angles of 1 degree.

Ka-band: Doppler accuracy at Ka-band is mostly affected by the Earth-spacecraft-Sun angle, and for X-band uplink/Ka-band downlink mode the one sigma accuracy is near that as described in X-band uplink/X-band downlink.

8.3.2 Ranging Data

Ranging data measures the time that it takes a series of signals superimposed upon the uplink carrier frequency to reach the spacecraft, be retransmitted, and then received at an Earth station (round-trip-light-time, RTLT). As such, all DSN ranging systems are intrinsically coherent.

The user of ranging data service must define two of three required parameters: the desired accuracy, the desired range measurement ambiguity, and the maximum observation time. These along with the knowledge of the received ranging power-to-noise ratio will allow for the configuration of the ranging system.

(1) Sequential Ranging

The 26m, 34m, and 70m subnets utilize the DSN Sequential Ranging Assembly (SRA). For strong signals the SRA can provide measurements of the range to the spacecraft to 1 meter precision at X-band and to 2 meters precision at S-band. However, data accuracy is a function of signal strength and for ranging data via a spacecraft low gain antenna at typical deep space ranges, the data accuracy may be degraded to as much as 1 km.

The SRA modulates a series of codes upon the radio signal to the spacecraft. The first of these, the "clock code," defines the resolution or accuracy that the ranging measurement will have. However, the observation from the clock code is ambiguous as it only identifies the fractional part of the clock code period comprising the RTLT, there are an unknown additional integer number of clock periods composing the RTLT. The SRA, then sequentially modulates a decreasing series of lower frequency codes upon the signal in order to resolve the ambiguity in the range measurement, by increasing the period of the ranging code. The maximum range ambiguity possible in the DSN ranging system is approximately 152,000 km, however ambiguities of 1,190 km and 2,380 km are more commonly used.

The accuracy of a ranging observation is a function of the received power-to-noise ratio in the ranging signal. Greater accuracy can be achieved by observing the "clock code" signal for a longer period of time. For lower power-to-noise ratios it also takes longer to resolve each of the ambiguity resolution codes. Consequently, for a given power-to-noise ratio, a desired accuracy and a desired ambiguity will result in a required observation time. For practical purposes the maximum value for this observation time is 30 minutes. In the event that the desired accuracy and desired ambiguity result in a required observation time greater than 30 minutes, either a change in the ambiguity or the accuracy will be required. DSN Document 810-5, Module 203[6] provides a detailed description and the formula used in calculating the accuracies.

(2) 26m Ranging

In addition to the SRA, the 26m subnet also supports a second order ranging system which is a hybrid system combining a harmonic side tone ranging system with a binary encoded ambiguity resolving code. This system operates only at S-band and provides a measurement accuracy varying from 1 to 10 meters for Earth orbiting spacecraft. The ambiguity of the measurement is 644,000 km. DSN document 810-5, Module 204 provides a detailed description of the ranging system.

8.3.3 Angle Data

The DSN 26m subnet has the capability to provide closed loop pointing to a spacecraft being tracked and to report the resulting azimuth and elevation of the antenna. This angle data which is primarily used to support low Earth orbiters and for launch support is accurate to approximately 0.02 degrees. Angle data does not require a coherent signal, but is only available at S-band. A customer wishing to receive raw angle data service would receive the data via DSN interface TRK-2-30.

8.3.4 Latency of Validated Radio Metric Data Service

At the present, the Validated Radio Metric Data Service routinely provides data products with a 24-hour turn-around time. For supporting time-critical mission events, a delay of 30 minutes to 1 hour in delivery of data can be achieved.

8.4 Radio Metric Orbit Determination Service Performance

The performance of the radio metric orbit determination is described in terms of an Earth-centered Earth Equatorial Radial-Transverse-Normal coordinate system. Accuracy is principally a function of the amount of tracking, Earth relative geometry, and data types utilized. The following captures the typical one sigma capability:

(1) Coherent Doppler only, spacecraft geocentric declination greater than 10 degrees --

Range: 10 km

Transverse & Normal: 250 meters for every 1,000,000 km from the Earth (e.g. 37.5 km at 150 million km geocentric range)

(2) Coherent Doppler only, spacecraft geocentric declination less than 10 degrees --

Range: 10 km

Transverse & Normal: 500 meters for every 1,000,000 km from the Earth (e.g. 75 km at 150 million km geocentric range)

(3) Coherent Doppler and Ranging, spacecraft geocentric declination greater than 10 degrees --

Range: <1 km

Transverse & Normal: 100 meters for every 1,000,000 km from the Earth (e.g. 15 km at 150 million km geocentric range)

(4) Coherent Doppler and Ranging, spacecraft geocentric declination less than 10 degrees --

Range: <1 km

Transverse & Normal: 150 meters for every 1,000,000 km from the Earth (e.g. 22.5 km at 150 million km geocentric range)

9 Description of Tool Delivery Process

The DSMS provides a suite of tools, in form of software components with or without a hardware platform, to customers for them to operate their missions and to develop their mission operations system (MOS). Since these tools are outside the scope of the basic TT&C services, **customers are required to make a programmatic arrangement with JPL for obtaining any of these tools.**

Figure 9.1 shows the customer interface for tools. There are three options for tools:

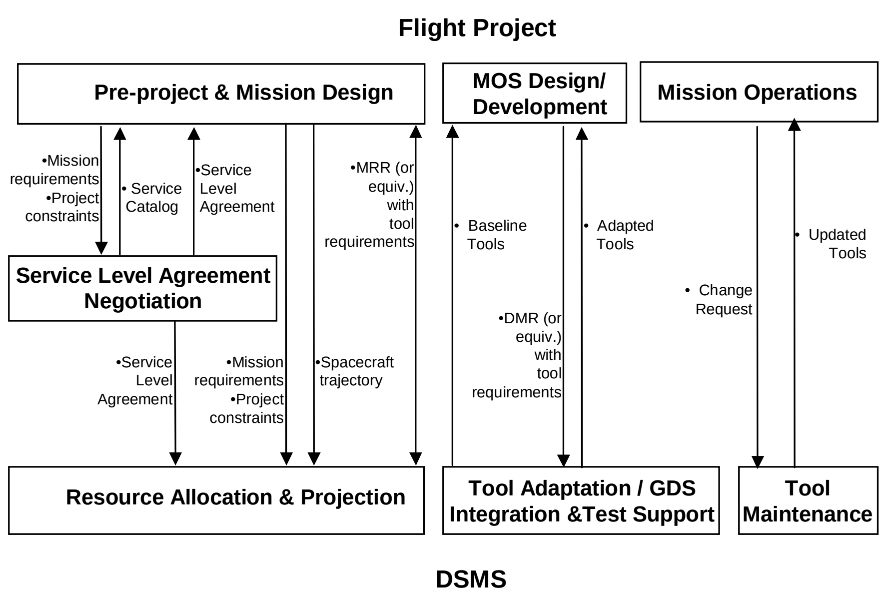
(1) DSMS delivers a core ground data system to the customer to develop a mission-specific GDS.

(2) DSMS supplies tools configured and tailored to meet the customer requirements. The customer is responsible for integrating the tool into their system.

(3) DSMS provides the tool as is, and the customer is responsible for customization and integration. This option is not available for all tools.

DSMS will provide maintenance of the tool over the life of the mission as negotiated. Different levels of maintenance are available.

Figure 9.1 Customer Interface for Tools: Process Over the Project Life Cycle



10 List of Tools and Functional Description of Tools

In addition to providing services, the DSMS includes an extensive set of mission operations tools which, when adapted and supplied to a mission, can be used to augment and extend a customer's existing systems (for example, the system used for mission integration and test) or commercial-off-the-shelf systems. A special tool, i.e., the core GDS, can also be supplied to build a mission-specific GDS. Tools are provided for all aspects of mission applications, from observation planning, scheduling/sequencing support, mission control, state tracking, prediction, to experiment data analysis support. These tools typically require adaptation, configuration or extension to meet a mission's unique requirements. The DSMS tool providers can adapt the tools as part of the tool-supply process to a mission. Alternatively, customers may choose to do the adaptation themselves.

For obtaining detailed information about specific tools, the customer is advised to contact DSMS personnel via the mechanism described in Sec.2. A Government-use license for temporary use of the following software tools may be obtainable through the JPL cognizant Government procurement officer.

10.1 Automated Command Tracker

This tool set provides functions to manage and track command files and to automate the command review and approval process. It includes functions to support electronic review and approval of command loads using secure means for user authentication.

10.2 Data Management Tools

The tools include data catalog capabilities with several query and access interfaces, both GUI and command line versions are available to support direct user access or automation. Data may be queried and fetched on demand and subscription capabilities are provided that can be programmed to automatically deliver different classes of data as it arrives. The data storage functions provide both open access and managed access modes to provide data security and access control as required. Storage is extensible to accommodate short term or life of mission applications and in some case the storage and catalogs may be distributed for load balancing. API's are provided to permit direct integration of the data management and catalog functions into other applications.

10.3 Telecommunications Analysis Tools

Telecommunications Analysis Tools generates link design control table showing the uplink and downlink telecommunications performance. It takes into account the configuration and characteristics of spacecraft telecommunication subsystem, the selected capabilities and configuration of DSN tracking stations, trajectory geometry, etc. for estimating future uplink and downlink signal strength, signal-to-noise ratios (SNR), best lock frequency, Doppler frequency offsets, etc. These predict tools may also assist customers in specifying the spacecraft telecommunication system parameters during the mission design phase.

10.4 Mission Control Tools

Mission control tools displays spacecraft engineering telemetry data for customers to monitor the health and safety of the spacecraft. It gives the capability to ingest, process, and display the data in real-time with a built-in automated alarm/alert mechanism. A spacecraft commanding tool gives the capability to generate real-time commands. Also provided are tools to monitor the ground system performance.

10.5 Navigation Ancillary Data Tools

The Navigation Ancillary Data Tools permit creation of reduced and interpreted ancillary datasets which may include spacecraft ephemeris, planetary ephemeris and constants, instrument descriptions, camera pointing, events about spacecraft and instruments. The output from these tools may be used to annotate observations or otherwise record mission analyses, events and processing states. Packaged as an integrated toolset, the Navigation Ancillary Information Facility (NAIF) tools have been used by many flight projects and PIs in a variety of different science domains. While providing generalized capabilities, they have to be adapted for use by a particular mission.

10.6 Planning and Scheduling Tools

Planning and scheduling tools are used to plan overall mission scenarios and observation sequences, to create schedules for communication, spacecraft, and instrument activities, to create command sequences and translate them into a form suitable for transmission to the spacecraft. Planning tools include resource analysis, link and resource forecasting, and predicts generation. The planning process may also make use of spacecraft and instrument simulators, trajectory generators, viewperiod predictors, and ephemerides which are described separately.

10.6.1 Sequence Planning Tools

These tools provide sequence generation, validation, and review capabilities for standard mission commanding scenarios. The inputs to these tools are the mission and observation plans, current spacecraft state, allocations of tracking passes, and associated viewperiod, lighttime, and other predicts. Output of these tools are validated command sequences suitable for uplink to the spacecraft, an integrated schedule of spacecraft and ground data system events, and other information used to predict and validate spacecraft operation.

10.7 Experiment Product Tools

A suite of tools is provided to process image, spectral, radar, time series, and other data forms. These tools may be invoked via a user interface which provides command line, GUI, and on-screen visual programming supported by extensive on-line help. The entire suite of tools may be used in a highly interactive data exploratory mode or programmed for automated processing of large data volumes.

10.7.1 Science Data Processing Tools

These tools are used to produce "level 1A&B" products generated in non-real-time after the creation of the raw level zero data products. This processing may include merging of telemetry data received from multiple sources into the best available set of data, removal of instrument signature, mathematical transformation of time series data, and data quality checks. Higher level processing may include true color reconstruction from multiple exposures, cartographic projections and generation of large image mosaics.

10.7.2 Science Data Visualization Tools

These tools are used to convert the science data products into forms that can be displayed or printed for visual interpretation. This may include animation sequences, mathematical transformation of time series data, visualization products portraying data from multiple instruments, and visualization products of multispectral data. Other tools are available to perform "data mining" operations, scanning large volumes of data for particular signatures or artifacts.

10.7.3 Cartographic Tools

These are the tools which can be used to support precise cartographic projections, derive elevation maps from stereo/SAR imagery, Cartographic projections for bodies other than the Earth including irregular bodies.

10.7.4 Instrument Development Tools

These are the tools used for instrument development in the following areas:

Calibration/Decalibration - Tools to support the calibration analysis for science instruments

Data Compression/decompression - Tools to support the selection and development of science data compression algorithms including simulation of an end-to-end data system covering the path from photon to final science product.

10.8 Spacecraft Test Tool

DSMS provides a spacecraft test tool to support the flight system development and test. It is available in two different forms. First, the Test Telemetry and Command Subsystem (TTACS) Core allows data to flow to and from the spacecraft without the operational ground/spacecraft interfaces. It provides serial telemetry and command interfaces between the spacecraft GSE and specially configured command and telemetry software resident at the various workstations.

(1) a high-speed serial device for the interface with spacecraft GSE,

(2) the Test Telemetry Interface (TTI) software that receives and processes the telemetry data from the test spacecraft hardware and transmit it to the other GDS components in the testbed environment

(3) the Test Command Interface (TCI) software that processes command files from the GDS components into blocks of command bits and delivers them to the test spacecraft hardware.

The second form of the test tool is the Test Telemetry and Command Subsystem (TTACS), which is essentially a miniature version of its counterparts in the operational system with a configuration needed to support the development and test of the spacecraft and MOS. Varying from project to project, it can be configured to include, in addition to the TTACS Core, certain number of parallel telemetry streams, finite number of data rates, a few workstations, data management capabilities, GSE interface, instrument BCE connections, etc. A final configuration of the TTACS is used to support the pre-launch system tests.

10.9 Core Ground Data System

DSMS supplies a core ground data system (CGDS) as a turnkey system for customer to build from it mission-specific GDS. The CGDS includes computer platforms and a complete, integrated, suite of tools described above in this section. Adaptation of any part of the CGDS for mission-specific needs can be provided by DSMS personnel or flight project itself. On-going maintenance of the CGDS during the project life cycle will also be available.

11 Engineering Support Activities

DSMS engineering personnel will be available to support customers in conducting pre-project studies, mission design, development of data systems, and/or the operations of missions. In general, these are level-of-effort support activities. The scope of each engineering support activity will have to be assessed on a case-by-case basis.

11.1 Support to Systems Engineering

DSMS engineering personnel can provide systems engineering support to missions to assist them in defining an end-to-end telecommunications and mission operations system architecture, defining operations concepts, identifying system solutions, and defining interfaces.

11.2 Support to Advance Mission Planning

DSMS engineering personnel provides engineering support to the planners of future missions in identifying and verifying their requirements for DSMS services, proposing or assessing telecommunication design for ensuring its compatibility with DSN, and analyzing optimal tracking and data acquisition approach.

11.3 Support to Configuration Management

Support can be provided to customer in the configuration management (CM) of the MOS and GDS. This includes giving assistance and advices to customer in establishing CM tools, data bases, and procedures, so that the flight project can have an operational CM system without having to develop its own system from scratch.

11.4 Support to Emergency Mission Operations Center

For a customer subscribing to the use of the Emergency Control Center (ECC) provided by the DSMS, engineering support will be provided to the contingency flight team in getting the data system, e.g. work stations, tools, and network connections, into operable state. (Note: The ECC is a scale-down version of the mission operations center. One of its purposes is to allow the customer to resume its flight operations in the event of a natural disaster or other catastrophic event which disables certain facilities of a mission operations center.)

11.5 Support to End-To-End Integration and Test

During spacecraft development phase, DSMS engineering personnel participate in the integration and test activities involving the DSMS-provided mission operations services. Support to testing the end-to-end telecommunications link and characterizing spacecraft telecommunications subsystem prior to launch and during flight operations can also be provided.

11.6 Support to RF Compatibility Test

Before launch, RF compatibility test equipment will be available for customer to validate the RF interface compatibility between the spacecraft and DSN. The compatibility test equipment emulates the data modulation/demodulation capabilities and provides an RF link between the user spacecraft and tracking stations.

11.7 Support to Telecommunications Design

The telecommunications design can be conducted during mission design phase to help a customer achieve a flight segment telecommunications design which is compatible with the space-ground link and capabilities of DSN tracking stations, and will achieve the desired level of performance. Design issues, potential deficiencies and possible trade-offs are identified through these analyses. In general, the support is dependent on project phases:

(a) Phase A (Preliminary Design): Initial telecommunications link design includes trial selection of transponder or transceiver, power amplifier, antenna type, data rate determination, and channel coding schemes. The purpose is to assess feasibility and derive initial cost estimates. Also, basic tracking support issues are identified, e.g. required DSN capabilities, tracking schedule, navigation data types, and mission unique features.

(b) Phase B (Detailed Design): Detailed design includes final selection of spacecraft telecommunications components, transponders, power amplifier, antenna patterns, trajectory geometry, function cross strapping, and redundancy management. Link losses based on spacecraft dimensions and coax or waveguide selections are included with ground antenna G/T curves, spacecraft pointing models, Doppler and Doppler rates, for all link functions, i.e. telemetry, command, ranging, and radio science if present.

(c) Phase C/D (Implementation, Integration, and Test): All of the design work of Phase B is maintained with measurements of actual flight hardware performance. Performance estimates are adjusted by changes in values from their earlier estimates, as well as by reductions in uncertainties allowed by measured versus estimated values. Discrepancies are analyzed for their effects and corrective actions. Mission operations adaptations are completed, sequences are built for testing on the spacecraft and for use in flight. Compatibility with the DSN is proven by test, and end-to-end tests from mission operations system to spacecraft.

11.8 Spectrum and Frequency Management

The DSMS Program Office is responsible to NASA and the international Space Frequency Coordination Group (SFCG) in managing deep space spectrum and frequency resources. In that capacity, the DSMS engineering personnel helps the customer license the use of the RF spectrum, performs conflict analysis, makes frequency allocation and interference avoidance/mitigation recommendation, and handles the licensing process with other government agencies.

11.9 System Administration

The DSMS system administrators install and configure mission-related workstations, routers, and firewalls. This may include both MOS software and third-party software installation.

11.10 Security Engineering

The DSMS Security Engineer arranges all interconnections between the (closed) Flight Operations Network and the (open) Internet. The primary path is through the DSMS Firewall. Security engineering support may be provided to the requesting Flight Project. This includes preliminary design and cost estimates for end-to-end network security.

11.11 Spacecraft Search

In time of severe spacecraft anomaly causing the loss of communications with the ground, the DSMS can provide equipment, e.g., high-power transmitter and high-sensitivity receiver, as well as personnel support to s flight projects for re-establishing contact with the spacecraft.

The ability to search for a lost spacecraft depends on the number of places that need to be searched, and on the signal level. There can be several dimensions in the search region: frequency, frequency rate, direction (ephemeris) and perhaps time, if the signal may be time varying. The difficulty of the search, or the time required for the search, increases approximately proportionally to the size of the search region, and inversely with assumed minimum possible SNR.

One dimensional searches, such as just over frequency, are fairly easy, as are two-dimensional searches over limited regions, such as over small uncertainties in frequency and frequency rate or space. Large two dimensional searches are very difficult, but can be done with the custom capabilities.

The Spacecraft Search capabilities offered are further divided into 6 types of services according to the techniques, complexity, and expertise involved in service provision: Frequency and Time Searches, Spatial Search, Frequency Rate Search, Extreme Weak Signal Search, Wideband Spatial Searches, and Extremely Weak Signals with Frequency and Frequency Rate Uncertainty.

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12 Pricing of Services

As NASA moves to a full cost accounting model, it is important that the pro-rata share of each service's cost be determined and budgeted by each mission. This section provides some pricing information intended to assist customer in estimating the DSMS service costs.

12.1 DSN Utilization Cost for TT&C Services

The DSN utilization cost is an essential portion of the total MOS cost for a mission. It can be computed from an "aperture fees"-based empirical algorithm described in this section. The algorithm was established by the NASA Headquarters more than 10 years ago and has been maintained by NASA official authority since then.

The DSN utilization cost covers the subscription fees for the following DSMS standard services:
(1) Command Services
(2) Telemetry Services (except Telemetry Channel Service)
(3) Tracking Services, i.e. Radio Metric Data Services (both raw and validated)
(4) Ground Communications Services (except dedicated circuit and LAN provision)
(5) DSN Science Services, i.e. Radio Science, Radio Astronomy/VLBI, and Radar Science Services
(6) Beacon Tone Service

The algorithm for computing DSN Aperture Fees embodies incentives to maximize DSN utilization efficiency. It employs weighted hours to determine the cost of DSN support. The following equation can be used to calculate the hourly Aperture Fee (AF) for DSN support.

$$AF = R_B [A_W (0.9 + F_C / 10)]$$

where:

AF = weighted *Aperture Fee* per hour of use.

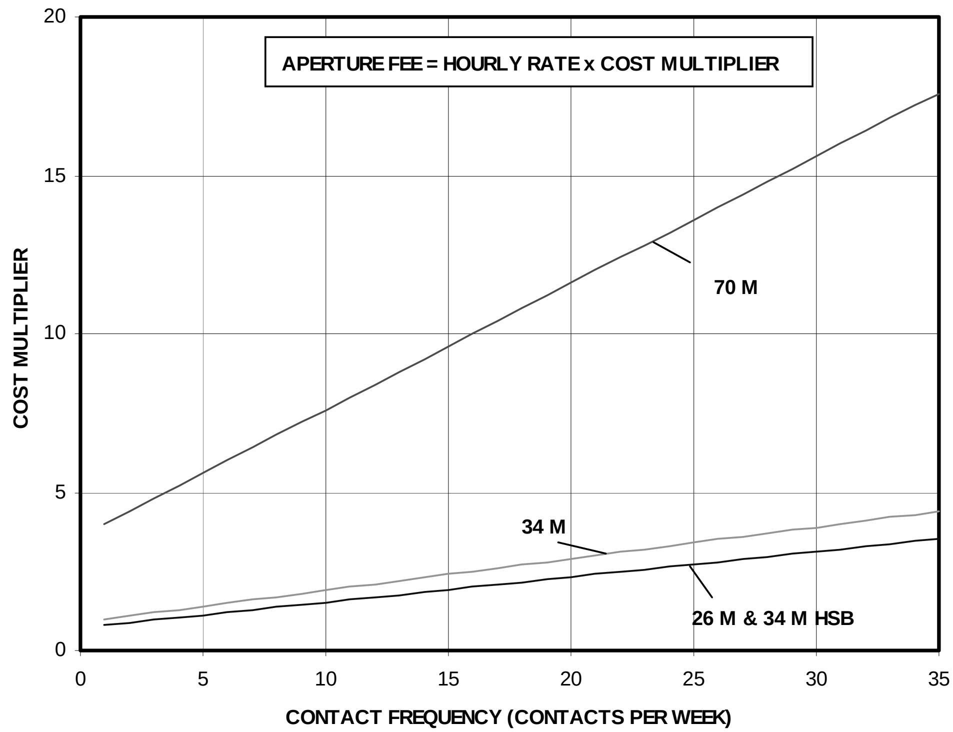
R_B = base hourly rate = $767.00/hr in FY 2002 dollars).

A_W = aperture weighting:
= 0.8 for 26-meter stations.
= 1.0 for 34-meter stations.
= 4.0 for 70-meter stations.

F_C = number of station contacts, (contacts per calendar week).

The weighting factor graph in Figure 10.1 shows relative antenna costs. A station contact may be any length but is defined as the lesser of the spacecraft's view period or 12 hours. Total DSN cost is obtained by partitioning mission into calendar weeks and summing the Aperture Fees. This total cost can be obtained by grouping weeks having the same requirement, multiplying by Aperture Fee, and summing over the mission's duration. An Excel spreadsheet is available at the Homepage [TBD] to help customers establish the DSN cost estimate for their missions.

Figure 10.1 Aperture Weighting Factors and Cost



For each station contact, i.e., a tracking pass, there is the need for calibrating and testing the configured equipment prior to the supported event. The time period for such activity is known as the pre-calibration time. Similarly, there is the need for configuration reset after a supported event. The time taken for the latter is known as the post-calibration time. Both pre-calibration and post-calibration times are part of the aperture time cost-attributable to customer. For a regular station contact, the pre-calibration time is 45 minutes and the post-calibration time is 15 minutes. For a station contact providing only Beacon tone service, however, they are 15 minutes and 5 minutes, respectively.

12.2 Policies on Non-recurring Costs of Services

A few policies have been established to guide the determination of non-recurring costs associated with services. In general, non-recurring costs are negotiated by the customer and DSMS personnel based on the project requirements, scope of the adaptation, and agreed levels of customer support. Recurring costs are derived from standard tables such as the DSN aperture fee base rate, operational network rates, and wide area network circuit fees.

12.2.1 Performance-based Non-recurring Costs

Subscribers to standards services requiring better performance than provided by the standard services will be charged non-recurring costs. Examples include:

- Continuity requirement (for telemetry services) better than 8 gaps in 10,000 packets
- Completeness requirement (for telemetry services) better than 95% during mission life

12.2.2 Content-Independent Services

Subscribers to standard services which are content-independent generally have no non-recurring cost to begin use of the service. This reflects the plug and play and standard interface attributes discussed above. In these cases adaptation includes establishing labels, parameters, addresses, and other selections that are bounded by the normal scope of that standard service. Examples of services supplied at a simple recurring cost are:

- Command Radiation/Delivery
- Telemetry Frame, File services
- Radiometric data services
- Beacon Tone
- DSN Science services

12.2.3 Content-Dependent Services

Subscribers to tailored services, or to standard services which have significant content dependence, can expect a non-recurring cost to make the necessary adaptations. Examples of services which typically have non-recurring cost are:

- Mission Data Management
- Navigation (OD, Trajectory, Maneuver, etc.)
- Experiment data products
- Flight Engineering

12.3 Fee for Other Services

For cost estimate regarding other types of services as well as all the DSMS-provided tools and engineering support, a "grass-root" design-based costing exercise is highly recommended. For missions in conceptual design and planning phases, typically, this is conducted by an engineering team organized by the DSMS Program Office, at a nominal expense to the customer. Customers are advised to contact the DSMS Program Office (see Section 2 of this document for Point of Contact) for details.

13 Acronyms and Abbreviations

AMMOS	Advanced Multi-Mission Operations System
API	Application Program Interface
ARQ	Automatic Retransmission Request
BCE	Bench Checkout Equipment
BWG	Beam Waveguide
CCSDS	Consultative Committee for Space Data Systems
CDE	Consolidated Development Environment
CLTU	Command Link Transmission Units
DFS	Distributed File System
DN	Data Numbers
DSCC	Deep Space Communications Complexes
DSMS	Deep Space Mission System
DSN	Deep Space Network
EPS	Earth-Spacecraft-Sun
ERT	Earth Receive Time
EU	Engineering Units
FTS	Frequency and Timing Subsystem
GDS	Ground Data Systems
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GUI	Graphic User Interface
HEF	High Efficiency
ICC	Integrated Computer Complex
ICT	Integer Cosine Transform
IGSE	Instrument Ground Support Equipment
ISO	International Organization for Standards
ITU	International Telecommunication Union
JPEG	Joint Photographic Engineering Group
MADB	Missions & Assets Data Base
MOS	Mission Operations System
MSM	Mission Service Manager
MSPA	Multiple Spacecraft Per Aperture
NAIF	Navigation Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NISN	NASA Integrated Service Network
NSSDC	NASA Space Science Data Center
OD	Orbit Determination
ODRC	Operations Data Reduction Complex
PCD	Project Commitment Document
PDS	Planetary Data System
POCC	Payload Operations Control Center
PSLA	Project Service Level Agreement

820-100 DSMS Services Catalog

QQCL	Quality, Quantity, Continuity and Latency
RF	Radio Frequency
RMDC	Radio Metric Data Conditioning Service
RSS	Radio Science Services
RTLT	Round-Trip-Light-Time
SCPS	Space Communications Protocols Standard
SFCG	Space Frequency Coordination Group
SLA	Service Level Agreement
SLE	Space Link Extension
SNR	Signal-to-Noise Ratio
SOMO	Space Operations Management Office
SPICES	Spacecraft Planetary Instrument Camera Event
SRA	Sequential Ranging Assembly
TDM	Time Division Multiplexed
TDRS	Tracking and Data Relay Satellites
TMO	Telecommunications & Mission Operations
TMS	Telecommunications & Mission Services Manager
TTACS	Test Telemetry & Command Subsystem
UTC	Coordinated Universal Time
UDP	User Datagram Protocol
VCDU	Virtual Channel Data Units
VLBI	Very Long Baseline Interferometry